

## **Reflective Light Modulation by Cephalopods and Fishes in Shallow Nearshore Habitats**

Roger T. Hanlon

Marine Biological Laboratory, Woods Hole, MA 02543  
phone: 508 289-7710 fax: 508 289-7900 email: [ghanlon@mbl.edu](mailto:ghanlon@mbl.edu)

Charles F. Chubb

Department of Cognitive Sciences & Institute for Mathematical Behavioral Sciences  
University of California at Irvine, Irvine, CA 92617  
phone: 949 824-3517 email: [cchubb@uci.edu](mailto:cchubb@uci.edu)

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### **LONG-TERM GOALS**

The central question is: what are the optical principles upon which crypsis is achieved by opaque organisms in shallow, nearshore marine habitats?

### **OBJECTIVES**

Camouflage mechanisms are not well known despite the general misconception that they are. Moreover, quantification of camouflage (especially of opaque organisms) is particularly wanting. We have four objectives: (1) Acquire imagery of camouflaged animals and their backgrounds in coral reef and temperate rock reef environments; (2) collect corresponding *in situ* irradiance data from the animal and background; (3) Develop a suite of image analysis methods to quantify the type and degree of crypsis; (4) Construct a comparative digital photographic and video library of shallow-water marine animals in the camouflage categories of Uniform, Mottle and Disruptive. The central focus is on cephalopods (octopus, cuttlefish and squid) because they have the most diverse and changeable camouflage patterns known in biology. Several fishes with changeable coloration (groupers and flounders in particular) are studied comparatively.

### **APPROACH**

High-resolution digital still images (Canon EOS 1Ds, Mark II camera) are acquired under natural marine conditions. No flash is used to avoid making artificial shadows from the flash light. A computer-controlled spectrometer (adapted for underwater use) takes downwelling and sidewelling irradiance data at the exact time of photography; then the animal reflectance data are recorded with the spectrometer (in both gross and fine detail on the animal's body) so that color- and contrast-matching can be quantified in the digital images. HDTV video is used to follow foraging cephalopods and fish to document (a) speed of body patterning changes and (b) the range of microhabitats that they encounter

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and the pattern they choose to camouflage themselves in each microhabitat. Laboratory experiments are conducted occasionally to support or test field findings. Image analysis programs are being developed in a MATLAB toolbox to enable quantitative analysis of crypsis.

R. Hanlon conducts the field work, participates in image analysis and publication, and directs the grant project. This year, field assistants included technician Justine Allen and masters student Anya Watson, both in the Hanlon lab. We formally recruited Dr. Charlie Chubb as Co-Investigator to lead the efforts on image analysis. Dr. Chubb has extensive experience in this field and brings a wealth of quantitative skills to this set of tasks. He is assisted in this task by Dr. Liese Siemann (who works part-time on this grant) and, very recently, by Derya Akkaynak who is a new PhD candidate in the MIT/WHOI joint program. Ms. Akkaynak will be formally co-mentored by Hanumant Singh of WHOI and R. Hanlon of MBL, with collaboration involving C. Chubb and L. Siemann. Her participation will enhance our progress on quantitative image analysis as well as the field acquisition of imagery data.

## WORK COMPLETED

**Field work** continued at a vigorous pace during 2009. RTH completed 4 field trips (total of 70 SCUBA dives), acquired 3,942 high-resolution digital still images of cephalopods and fishes, and recorded several hours of High Definition TV (HDTV) video. Briefly, the breakdown is as follows. (1) Bonaire, N. Antilles, March 2009 to photograph *Octopus vulgaris* and various fishes on coral reefs. (2) Little Cayman Island, April 2009 to videotape and photograph camouflage color change in Nassau groupers and small filefish. (3) S. Australia and NSW to study giant Australian cuttlefish as well as 2 other cuttlefish species. (4) Vigo, Spain (NW corner of Spain, Atlantic coast north of Portugal), September 2009 to film cuttlefish, *Sepia officinalis*, using camouflage for both defense and for prey hunting. Collectively, these five locations represent a wide variety of coral reef and rock/kelp reef habitats.

**Image analysis** this year centered once again on development of a suite of methods to be used as evaluation tools for camouflage effectiveness. We now have a MATLAB toolbox that incorporates a variety of texture and feature detection methods into one program. To allow flexibility, the program can be altered to incorporate different animal templates or analysis methods as needed. Summary statistics generated by the program can be used to characterize animal and background textures. Statistics summarizing the presence or absence of features, such as edges and corners, on the animal and the animal's biological edges are also generated.

The suite of methods includes texture statistics that characterize the scale of contrasting objects on the animal and in the background (granularity statistics and 2<sup>nd</sup> order structure-based intensity statistics). We have found that camouflaged cuttlefish reliably match the scale of contrasting objects in their surroundings. This has allowed us to begin developing a program that will use texture statistics to predict the body pattern a cuttlefish will choose on different visual backgrounds.

**Concept development** of camouflage visual mechanisms progressed well this year. In addition to a key publication involving the concepts of background matching and disruptive coloration (Hanlon et al., 2009), R. Hanlon organized and conducted a special 3-day workshop entitled **The Art and Science of Camouflage and Communication** in April 2009. This workshop involved 11 panelists that included an artist, nature photographer, architect, fashion designer, lighting expert, neurobiologist, two visual perception experts (C. Chubb was one of them), and two biological coloration experts. It was

highly interactive and multidisciplinary, and we believe it stimulated a good deal of concept development.

Our work in Vigo, Spain in Sep 2009 uncovered another finding: camouflage being used by cuttlefish against fish prey. Camouflage is most often considered as a defense mechanism, but here the cuttlefish were clearly using different camouflage patterns and approaches to get near schooling fishes near the substrate, then attacking them upon close encounter.

## RESULTS

**Cryptic patterning in large and small fish.** One key question in camouflage effectiveness is how well certain patterns scale up; that is, does a certain pattern seen in a small animal work on a large animal? If so, on what type of visual background will it work? To that end, we have been seeking locations where we can find large groupers and see if they (i) can change their camouflage patterns, and (ii) use the same range of camouflage patterns as small groupers. As reported last year, we had an initial good photographic base on Nassau groupers indicating that they use the 3 basic camouflage pattern types that we discovered in cephalopods: Uniform, Mottle and Disruptive (UMD); we also presented information on similar patterning in Goliath groupers.

This year, with Masters Student Anya Watson, we revisited Little Cayman Island to photograph and videotape Nassau groupers in more detail. We acquired an additional 768 photographs of groupers and several hours of videotape, and can now quantitatively and qualitatively characterize U, M, and D camouflage patterns in Nassaus both from the lateral and vertical viewpoints. The greatest degree of change takes place on the ventral aspect of the side of each fish; this is thought to enable countershading when the fish moves in the water column. Speed of change has been determined from video tapes. There is sufficient imagery to evaluate the patterns that are used in various soft and hard coral backgrounds and these will be presented later in 2009 as she concludes her masters thesis.

We also made a surprising discovery: a small filefish (2-3cm) that changes in 1-2 seconds and shows Uniform, Mottle and Disruptive camouflage patterns (Fig. 1). In addition, this amazing little fish also has controllable skin papillae that aid camouflage; no fish has been reported to have this capability although it is common in cephalopods (Allen et al., 2009). These data will be analyzed soon.



**Figure 1. The slender filefish *Monocanthus tuckeri* with changeable camouflage, showing Uniform, Mottle and Disruptive patterns on different backgrounds and postures.**

**Patterning types and 3-dimensional texture.** Two papers listed below in publications (Allen et al., 2009; Chiao et al. submitted) address two key issues in animal camouflage. Skin papillae in cuttlefish and octopus are dynamically adaptive and the Allen et al. (2009) paper shows experimentally that this capability is controlled by the visual system of the cuttlefish. Papillae contribute to the 3-D texture match to the visual background. Importantly, this paper was conceived during our field work and inspired by the field images on this grant (some of which are included in the paper). Moreover, we have now discovered a fish species (Fig. 1) that can also adjust skin papillae. The second paper (Chiao et al., submitted) is a major work that characterizes one of the most common animal camouflage patterns known – Mottle (which is used extensively by the military). This paper will enable us to begin to sort out some statistical correlations involved with the mechanisms of background matching and disruptive coloration.

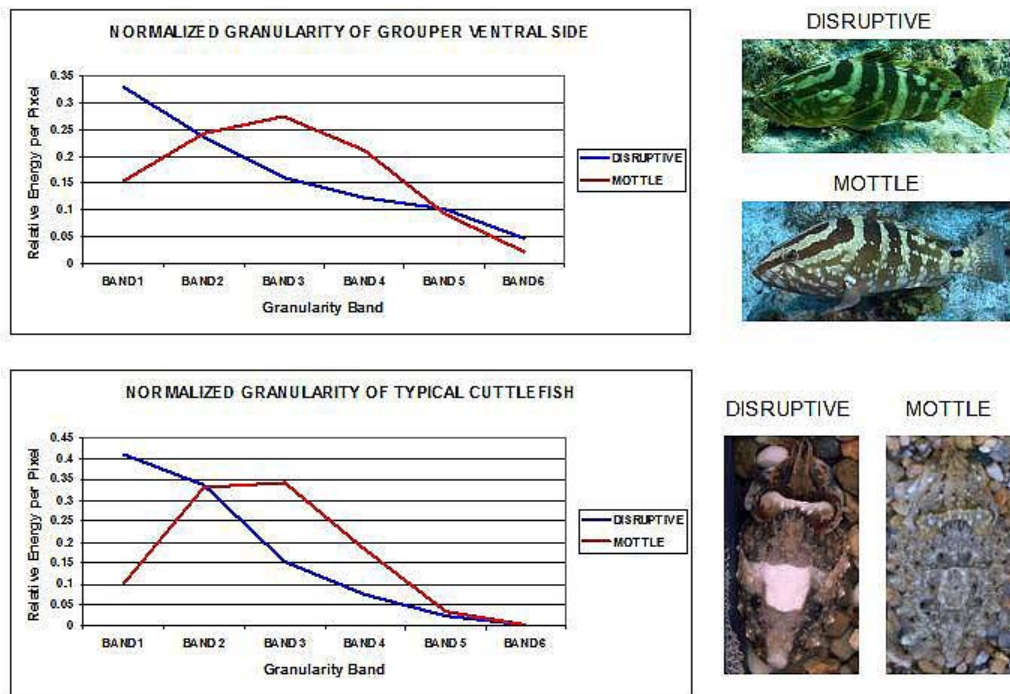
***In situ* irradiance data.** Two efforts were emphasized this year. First, we collaborated with USMA (West Point) to use Hyperspectral Imaging (HSI) to quantify camouflage in cuttlefish and flounder on natural background materials in the laboratory. This technology allows a quantum leap in capability since it combines imagery (a camera image) with many spectra (dozens/hundreds more than RGB digital camera; similar to spectrometer) in a single instrument. The results have been impressive and a paper is being prepared. Second, we analyzed the *in situ* irradiance data we acquired the past 2 years on giant cuttlefish in Australia and we are preparing a publication on that as well.

## **IMPACT/APPLICATIONS**

Our research this year on Nassau groupers complements last year's imagery on Goliath groupers and shows how Mottle and Disruptive camouflage patterns work on relatively large fishes in a coral reef environment. Disruptive works partly by background matching but also by obscuring the recognizable outline or shape of the animal, and we now have the imagery to compare animal to background. Our "granularity program" that quantifies animal body patterns (based on fourier transform of the image and classification by spatial scale and contrast) has now been translated to use on fish (all of it has been developed thus far on cuttlefish) and is found to be robust for body shapes that are larger and

different from cephalopods (Fig. 2). This granularity program, developed by C. Chubb, is proving to be a useful tool and we will continue to use and refine it.

Our collaborative work with West Point on Hyperspectral Imaging (HSI) shows great promise. The goal is to streamline the acquisition, interpretation and functionality of light field data as it relates to the predator's view of camouflaged prey organisms such as cuttlefish and flounder. Our intent is to develop this for use underwater.



**Figure 2.** *Nassau grouper patterns (characterized by the granularity program) of Disruptive and Mottle compare well with curve shapes of Disruptive and Mottle in cuttlefish.*

## TRANSITIONS

A few of our original ideas on mechanisms of camouflage are being considered by ARL and DARPA.

## RELATED PROJECTS

The PI has one related project sponsored by a military agency. We continue to benefit from that project in terms of developing a suite of methods that can be used for quantifying various aspects of camouflage. This has been immensely helpful in testing novel approaches to quantifying camouflage, a subject that has received only scant attention in any of the scientific fields.

A related project was conducted in June and July 2008 sponsored by a National Geographic Society Research Grant. The NGS grant was presented as augmentation to this ONR grant, and the objective was to acquire a large sample (i.e. >500) of 3D images of camouflaged cuttlefish both day and night, and to determine whether these animals color match as well at night as they do in the daytime. This

was reported in the 2008 Annual report. Since then, we have attempted two analysis methods but neither was satisfactory; we are still working on these data.

C. Chubb is PI on a grant from NSF (Perception, Action & Cognition) to analyze the dimensions of human visual sensitivity to various classes of textures. This research promises to have important implications for understanding how camouflage patterns operate to elude detection by human observers.

## **PUBLICATIONS**

Hanlon RT, Chiao CC, Mathger LM, Barbosa A, Buresch KC and Chubb, C. 2009. Cephalopod dynamic camouflage: bridging the continuum between background matching and disruptive coloration. *Philosophical Transactions of the Royal Society* 364: 429-437. [published, refereed]

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